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ORIGINAL ARTICLE

Bedload sediment and nutrient losses in agro-ecosystems of the Brazilian semiarid region

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Abstract The objective of this study was to quantify sediment production from drag, and the loss of organic matter and nutrients as a result of surface runoff in agro-ecosystems of the Brazilian semiarid region. Four watersheds were selected; all located in Iguatu, Ceará state, and characterized by native Caatinga vegetation (MN), thinned vegetation (MR), pasture (PAST), and subsistence agriculture (AGRS). Measurements were taken during the rainy season of 2011. As a result of surface runoff, sediment production by drag (soil drag) ranged from 27.74 kg ha^{-1} in AGRS to 580.74 kg ha^{-1} in MR. The losses of organic carbon (OC), Ca, Mg, P and K by sediment drag were higher in the natural ecosystems (MN and MR), and of Fe and Zn in the AGRS and PAST agro-ecosystems respectively. The higher erodibility of the Vertisols from the MR, MN and PAST systems, when compared to the Luvisol (AGRS system) resulted in higher sediment production. These results indicate that natural ecosystems of hyper-xerophylic Caatinga vegetation cause an increase sediment production by drag while agro-ecosystems such as PAST and reduced soil tillage on maize, produce an increase in the depth of surface runoff and in the OC levels of the sediment respectively. The loss of nutrients in agro-ecosystems of semiarid region is governed by the volume of eroded soil with rainfall. The management and conservation of soil and green roofs in watersheds should be taken into account in developing policy and plans for sustainability in the semiarid region.

Keywords Bedload · Caatinga · Hydrossedimentology · Land use · Nutrients

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Introduction

The Caatinga biome is set into the northeastern region of Brazil, and has been intensively exploited for farming in some areas. This biome is predominant, covering the equivalent of 11 % of the area of the country where the vegetation consists of trees that lose their leaves during the dry season. It is also one of the semi-arid regions most populous in the world, which, associated with its fragile environment, resulting in a critical scenario for agriculture and human development (Maia et al. 2007). These actions have led to limitations in production, resulting primarily in losses of soil, water and nutrients.

The seasonal and spatial variability of rainfall patterns, with precipitation mainly concentrated from January to May, associated with the erosivity of the rains and with human intervention, have changed the support capacity of the agro-ecosystems in the semi-arid region. The high erodibility of Luvisols, Planosols and Leptosols and Regosols, characteristic of the region, may be included as a factor favoring erosion and the degradation of the Caatinga biome (Maia et al. 2007; Giongo et al. 2011).

To this effect, the degradation of the soil and the water of the semiarid region have as its principal cause water erosion (Santos et al. 2007; Díaz et al. 2011). Moreover, the removal of vegetation and frequent slash and burn management in the Caatinga have affected the physical quality of its soils, their nutrient cycle (Wick et al. 2000; Aguiar et al. 2006; Sousa et al. 2012) and also changed the dynamics of the hydrological processes (Santos et al. 2011; Rodrigues et al. 2013). The management of native or cultivated vegetation alters the hydrological response to surface runoff, thereby producing sediment by drag, which results from a complex interaction of hydrological and geological processes (Puigdefabregas et al. 1999; Grimaldi et al. 2004; Owens and Xu 2011) naturally influenced by the geomorphology (Liying et al. 2013) and human actions (Bartley et al. 2006; Moreira et al. 2011). It should be noted that although there are studies on the production and transportation of sediments, mainly for perennial rivers in temperate and humid climates, little is known about the water–sediment process that occurs in semiarid regions (Reid et al. 1996; Bautista et al. 2007; Méndez et al. 2010). Due to the potential threat of sediment pollution on downstream areas, there has been a large research effort in recent years to determine the processes controlling water, sediment and nutrient loss in these areas (Bartley et al. 2006; Lobato et al. 2009; Santos et al. 2011; Rodrigues et al. 2013).

During the transportation of sediment, a detrital load is produced in watercourses, resulting from erosive action at the sides and on the bottom of the beds, and known as 'bedload', and a load resulting from detrital removal from the slopes known as 'washload' (Poleto and Merten 2006). As a consequence there are dissolved fractions, particles in suspension and bed material.

Indeed, the quantity and quality of the sediments produced by surface runoff, as well as the associated nutrients, are an important source of knowledge of the dynamics and balance of agro-ecosystems (Fernández et al. 2013) The dragged or transported nutrients may result in the depletion of the soil, and also may lead to the eutrophication of reservoirs (Bertol et al. 2007; Recha et al. 2013).

The objective of this study was to describe sediment production by drag, and quantify the loss of organic matter and nutrients as a result of surface runoff produced by rainfall patterns in different agro-ecosystems in the Brazilian semiarid region.

Materials and methods

Study area

The study was carried out in areas of Caatinga in the watershed of the Upper Jaguaribe river, in the south-central region of the state of Ceará, Brazil, which is owned by the Federal Institute of Education, Science and Technology at Iguatu (IFCE—Iguatu Campus). The selected systems are set in four watersheds located between coordinates: 6°23′42″–6°23′47″S and 39°15′24″–39°15′29″W (Fig. 1).

Watershed configuration and land use systems

The selected watersheds present courses having ephemeral runoff of the 1st and 2nd Strahler order (Santos et al. 2011). The geomorphic and physiographic features of the watersheds have been described by (Rodrigues et al. 2013), and the main land uses are thinned vegetation (MR), native vegetation (MN), pasture (PAST) and subsistence agriculture (AGRS) (Table 1). For MR, herbaceous plants with a height of over 1.50 m and a trunk diameter of more than 10 cm were kept. In the area of PAST, the species *Andropogon gayanus* Kunt was established (in 2010), being maintained in 2011. In the AGRS maize (*Zea mays* L.) was grown, adopting a reduced tillage

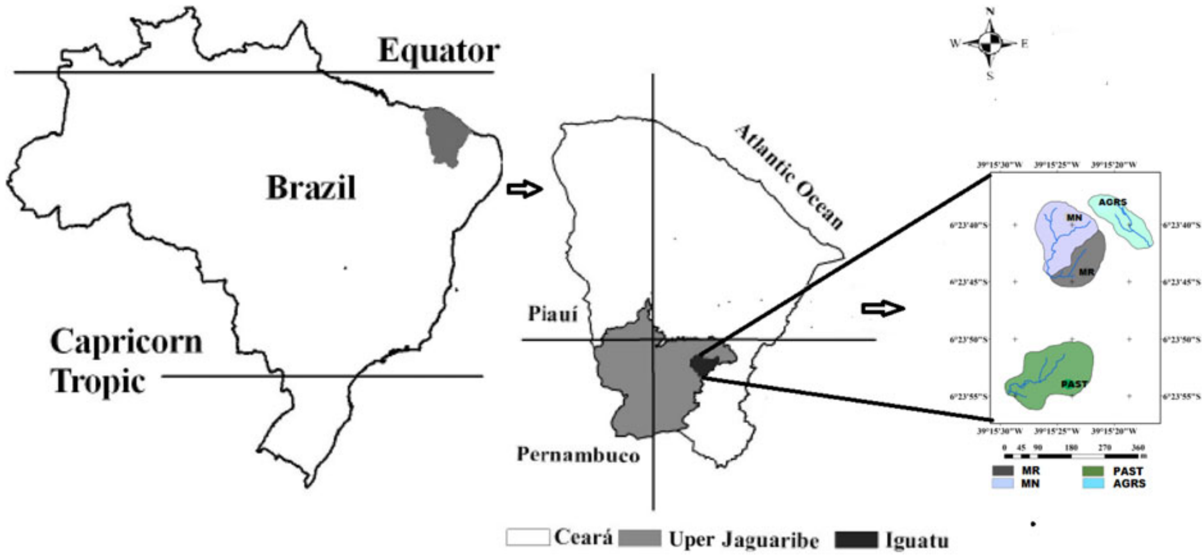

Fig. 1 Location of the study area in the state of Ceará, Brazil

Table 1 Geomorphic and physiographic characteristics of the areas and land use systems in the Iguatu watershed, Ceará, Brazil

Attributes	Agro-ecosystems				
	MR	MN	PAST	AGRS	Units
Area of the basin (A)	1.15	2.06	2.80	1.19	ha
Length of the basin (Cb)	188.17	204.40	253.90	208.50	m
Length of the main course (Cp)	147.18	252.11	238.20	150.30	m
Slope of the basin (Db)	8.72	10.59	5.57	10.63	%
Shape factor (Rf)	0.32	0.49	0.43	0.27	–
Drainage density (Dd)	153.80	192.59	146.29	209.41	m ha^{-1}

Source: Adapted from Rodrigues et al. (2013)

system of simple rows, with mowing and windrowing of the straw in March 2011.

The vegetation was characterized as scrub and tree closed. In some parts of the study area were observed absence of vegetation or vegetation smaller. In areas of the forest were observed shrub and tree species as *Aspidosperma pyrifolium* Mart and *Crotonsonderianus* Muell. Arg., and herbaceous plants as *Hyptissauaviolens* (L.) point, *Hypissp*. and *Croton* SP (Palácio 2011). It was also the herbaceous developed more intensely in the MR relative to MN. It is noteworthy that the shrub and tree lost leaves during the dry season.

Climate, geology and soils

In this work, the climate variables (number of events, values precipitation, rainfall intensity and erosivity) were extremely important to characterize the hydrological regime and its variability, as well as be able to relate the effects of vegetation resulting from land use on the blade runoff and sediment production by drag. The classification of soils, geology and defining the textures of watersheds helped in discussions and interpretation of results.

The climate in the region according to the Köppen classification (1948) is BSw'h', hot semiarid, with maximum rainfall between March and May, and average monthly temperatures exceeding 18 °C. Between 1974 and 2008 an average rainfall of 970 ± 316 mm and an average potential evaporation of around 1,988 mm yr^{-1} were recorded in the study area (Rodrigues et al. 2013).

The soils in the watersheds were classified by Palácio (2011) and, according to WRB—World Reference Base for Soil Resources (2006), corresponded to Calcic Vertisol, typical of MR, MN and PAST; and Calcic Luvisol (Abruptic, Chromic) typical of AGRS.

According to Palácio (2011) the texture of A horizons ranged from silty clay in MR and MN

(137 g kg^{-1} sand, 447 g kg^{-1} silt and 416 g kg^{-1} clay), to loam in PAST (315 g kg^{-1} sand, 425 g kg^{-1} silt and 260 g kg^{-1} clay) both with type 2:1 clay and loamy sand in AGRS (778 g kg^{-1} sand, 182 g kg^{-1} silt and 40 g kg^{-1} clay). The clay content in MR, MN and PAST decreased with depth while in AGRS there was a sharp increase in the clay content with depth, characterizing an abrupt textural change (WRB—World Reference Base for Soil Resources 2006). In the surface layers, acidity, organic carbon (OC) and other chemical characteristics were determined, according to Silva (1999), and the data analysis can be observed on Table 2.

Sampling and analytical determination

Each watershed was equipped with a *"Ville de Paris"* pluviometer, a Parshall gutter, sediment (bedload) collectors, automatic pluviographs and a data platform (DCP) for obtaining data at 5 min intervals, as described by Santos et al. (2011). The sediment collecting stations consisted of a trap-type pit (bed load) which was always placed upstream of the gutters to collect sediment from the edges and bottom of the bed after each generating event and it served to quantify sediment production by drag.

The collected sediments were air-dried and analyzed for potential acidity (H^{+} Al^{3+}), organic matter content (by wet oxidation) and nutrients [P, K, Na, Fe, Cu, Mn and Zn (Mehlich1extractor), Ca and Mg (KCl 1 M extractor)], according to Silva (1999). For the estimation of organic matter and nutrient losses, the sediment production by drag in 57 events and their respective nutrient levels were considered.

Table 2 Data from chemical analysis of the surface layer (0–25 cm) of representative soils from the agro-ecosystems of Iguatu

Chemical attributes	Agro-ecosystems			
	MR	MN	PAST	AGRS
pH (H_2O)	7.39	7.74	6.77	5.68
$H^{+}Al^{3+}$ ($mmol_c$ dm^{-3})	13.20	12.54	25.25	28.88
OC (g kg^{-1})	17.14	19.64	28.63	11.28
P (mg kg^{-1})	2.15	1.88	0.99	0.99
Na ($mmol_c$ dm^{-3})	1.96	1.44	5.93	0.78
K ($mmol_c$ dm^{-3})	5.55	4.09	2.76	1.71
Ca ($mmol_c$ dm^{-3})	400.84	405.02	247.39	27.26
Mg ($mmol_c$ dm^{-3})	61.02	59.93	98.86	13.40
Fe (mg dm^{-3})	5.51	4.19	11.16	59.97
Zn (mg dm^{-3})	1.46	2.30	2.62	0.75
Cu (mg dm^{-3})	5.15	4.40	2.48	0.83
Mn (mg dm^{-3})	23.10	23.52	24.15	12.50

Calculation of rainfall erosivity

From the values of the precipitation obtained, and with the spatial variability discarded due to the proximity of the watersheds, the intensity (I) of each event was calculated in mm h^{-1} and the maximum intensity in 30 min (I_{30}) in mm h^{-1}. Using the equation proposed by Wischmeier and Smith (1978), modified by Foster et al. (1981), and quoted by Santos et al. (2007) the kinetic energy (Ec) associated with the precipitation in MJ ha^{-1}, was obtained as follows:

$$Ec = 0.119 + 0.0873 \log \mathrm{I}$$

where: I—the intensity of the precipitation (mm h^{-1}).

The erosivity of the precipitation (EI_{30}) in MJ mm ha^{-1} h^{-1} was determined considering the associated kinetic energy (Ec) and the maximum intensity of the precipitation in 30 min (I_{30}), from the equation:

$$EI_{30} = \left(\frac{\sum Ec * I_{30}}{100}\right).$$

where: Ec—kinetic energy of the precipitation per unit area (MJ ha^{-1}); I_{30}—maximum intensity of the precipitation in 30 min (mm h^{-1}).

Statistical analysis

To identify the soil characteristics that contributed to the discrimination of land use systems, Principal Component Analysis (PCA) was used to identify those with the greatest weight among indicators of the process, i.e. explaining the corresponding percentage of variance (Vialle et al. 2011). To do so, the steps for the standardization (auto-scaling) of the measurements were followed, in order to minimize the effects of different measurement scales generating a zero average and unit variance. A biplot graph of the normalized levels of organic matter and nutrients from sediments (loadings) and of the factors related to the land use systems (scores) was created using the Statistica software (Statsoft Inc. 2007).

Results and discussion

Analysis of rainfall in the study area

A total of 57 rainfall events were recorded in the watersheds, with a total of 1,457.29 mm from January to May 2011 (Table 3), which is an atypical rainfall (top 50 %) for the selectd semiarid region. However, the high rainfall during the study period allowed an assessment of the process of erosion and an estimate sediment production by drag in the different watersheds. Soil erosion has long been recognized as a process closely related to the kinetic energy of rainfall in the form of the erosivity index (EI_{30}). (Méndez et al. 2010; Santos et al. 2011).

Three rainfall events (>60 mm), with high erosivity (>800 MJ mm ha^{-1} h^{-1}), were recorded at the beginning of the rainy season (January and February). Both values are similar in magnitude to the reported by Méndez et al. (2010) in semiarid Central Mexico. However average rainfall and rainfall intensities (I_{30}) were higher in April 2011 (Table 3), when both parameters reached 35 % of the total observed for the year. High rainfall is usually recorded in April in the region, with intensities that may reach 25 mm h^{-1} (Rodrigues et al. 2013). Also, in April we observed the highest erosivity, a fact that influenced sediment production. Similar data were verified by Santos et al. (2007) in a Haplic Luvisol in the semiarid region of Paraíba state. The former found a high monthly dispersion of the precipitation and erosivity, reaching greater values in February and April (53 and 79 % respectively) and with a direct impact on soil erosion. The latter found higher rates of erosivity between January and March. The data indicate a high seasonal variability in the distribution of rainfall, with rainfall erosivity in April exceeding by 100 % that registered in the remaining months under evaluation for 2011 (Table 3). According Méndez et al. (2010) and Rodrigues et al. (2013) such characteristics, associated with the spatial variability of the rainfall, are critical in semiarid regions, since there are positive correlations between erosivity and soil erosion and the production of sediment.

Table 3 Number of events, precipitation values (PPT), maximum rainfall intensity in 30 min (I_{30}) and erosivity (EI_{30}) recorded in the rainy season of 2011 in the studied agro-ecosystems of Iguatu

Month	Events	PPT (mm)	I_{30} (mm h^{-1})	EI_{30} (MJ mm ha^{-1} h^{-1})
	Units	Total	Total	Total
Jan	13	298.50	286.62	2,325.94
Feb	11	274.33	329.87	2,237.62
Mar	07	92.43	139.92	652.61
Apr	17	512.19	585.12	5,112.91
May	09	279.84	272.21	2,387.97
Total	57	1,457.29	–	–

Runoff and the production of sediment by drag

The depth of surface runoff and sediment production by drag were higher in April 2011, as a result of the heavy rainfall in that month (Table 4). However, it should be noted that in AGRS, whose soil is classified as a Calcic Luvisol (Abruptic, Chromic), there had already been substantial surface runoff in February which may possibly be related to the presence of the abrupt textural change which may have caused a decrease in the saturated hydraulic conductivity of the soil, favoring surface runoff. In MR, MN and PAST, the cracking of the Vertisol may have contributed to storage of the early precipitation. However, once the soil is wetted and cracks have closed by the expansion of high activity clays (2:1; i.e. smectites), characteristic of those soils, the rate of water infiltration decreases sharply, which may have caused an increase

Table 4 Monthly values of surface runoff and sediment production by drag in the rainy season of 2011 in agro-ecosystems of the semiarid region, Iguatu

Attributes	Month	Agro-ecosystems			
		MR	MN	PAST	AGRS
Depth of surface runoff (mm)	Jan	0.63	5.71	20.33	16.40
	Feb	15.37	38.29	49.31	72.07
	Mar	0.00	0.38	0.00	0.10
	Apr	67.48	63.34	184.15	53.48
	May	59.69	80.14	143.57	40.87
	Total	143.15	187.87	397.36	182.93
Sediment production by drag (kg ha^{-1})	Jan	1.41	0.56	3.62	0.46
	Feb	178.52	84.87	73.12	11.62
	Mar	0.08	0.08	0.31	0.20
	Apr	249.12	139.75	111.21	10.87
	May	151.04	117.52	70.59	4.60
	Total	580.17	342.79	258.85	27.74

in the depth of surface runoff in these soils (Duiker et al. 2001; Spaargaren 2008).

The total depth of surface runoff in the watersheds was as follows: PAST> MN> AGRS> MR (Table 4), this sequence was recorded for runoff depths per event. This fact can be related to the soil texture, the soil infiltration capacity, (Santos et al. 2007; Méndez et al. 2010) and the geomorphic and physiographic characteristics of the watersheds (Moreira et al. 2011). In the wooded areas (MN and MR) and in PAST, the high clay contents in surface horizons (>40 %, for both MN and MR) and the presence of high activity clays (characteristic of Vertisols) have probably favored surface soil cracking, during dry season, which causes higher initial infiltration rates (Duiker et al. 2001) and also lower surface runoff. However, it is important to note that the MN watershed presents greater length of the main course, greater slope and greater drainage density in relation to that of MR (Table 1), which may partially explain the different depths of runoff. In AGRS, the initial infiltration is favored by the loamy sandy texture of the superficial horizons.

The ground cover can influence the rate of infiltration of the water (Franco et al. 2002; Santos et al. 2007; Méndez et al. 2010). Thus, the PAST with *A. gayanus* Kunt, being easy to lay and covering the surface of the soil, may have allowed for less water infiltration and higher surface runoff. The low-density drainage and smaller slope of the PAST system (Table 1) did not change the order of surface runoff in systems.

As regards the total volume precipitated, the runoff amounts ranged from 0.10 % in MR to 0.27 % in PAST, which is consistent with values observed in a Luvisol of an agroforestry system in the semiarid region of Ceará, by Aguiar et al. (2006). These authors have obtained 0.04 % in an area with thinned and reduced woody vegetation (silvo-pastoral system) and 0.43 % in an area subjected to the clearing and burning of the woody vegetation, and cultivated with maize and bean (traditional silvo-pastoral system). Santos et al. (2007) on a Stagnic Luvisol (Hyperochric) under hyper-xerophylic Caatinga obtained a surface runoff of 4 % of the total rainfall.

Sediment production can be defined as the transport of material per unit of time and area. In general, a fraction of sediments defined as bedload is little reported, either due to the time and effort needed for its measurement, or to the high spatial and seasonal variability of transport by drag (Reid et al. 1996; Oliveira and Cho 2009). In this study, the following sequence of sediment production by drag was observed: MR> MN> PAST> AGRS. The highest production was evidenced in Vertisols when compared to Luvisols. Due to the higher rainfall, greater intensity and erosivity, the largest sediment production was recorded in April. The sequence demonstrates that hyper-xerophylic Caatinga vegetation is not efficient in dissipating the erosivity or in reducing the impact of rainfall on the disaggregation of surface soil horizons and on the transport of sediment. In forested areas, the raindrops may be retained in the crowns of the trees, forming larger droplets which reach the ground. This fact may results in significant losses of sediments in natural ecosystems, when factors of soil and topography (Liying et al. 2013) favoring the sediment transport on watersheds. The sequence observed for sediment production by drag (Table 4) is consistent with the observations made by Aguiar et al. (2006) who recorded 550 kg ha^{-1} in an area of nature reserve, and 110 kg ha^{-1} in an area of intensive corn and bean cultivation. Santos et al. (2007), obtained a production by drag of 200 and 300 kg ha^{-1} for MN and littered undergrowth respectively also under a Luvisol in the semiarid region of Paraiba state.

In MR and MN, 37 events generating drag sediment were verified, whereas in PAST and AGRS, 42 and 40 were recorded respectively, with 57 being the total of events recorded during the evaluation period in 2011. Reid et al. (1996), determining the production of sediment by drag for a semiarid region in Israel, estimated it to be 8 % of the total sediment produced. Moreover, they noted a high variability in rainfall events, with sediment production by drag not being observed in 37 % of them. This may explain the amounts of sediment yield we observed, and higher sediment production by drag occurred in systems having less events. Similarly, the loamy sand texture of the surface horizon in AGRS may require more energy for transportation when compared the Vertisols (MR, MN and PAST) which present greater erodibility when wet (Duiker et al. 2001; Spaargaren 2008). It should be noted that sediment yield did not exceed 27.74 kg ha^{-1} in AGRS (Table 4), even when considering the higher of sediments the systems for slope and drainage density of the watershed (Table 1).

However, we noted the occurrence of water flow on the surface of the soil, and s sediment production by drag, which can be related to the soil internal drainage, i.e. with the increase in clay with depth in Luvisols, and with the type of clay in the case of Vertisols. It is noteworthy however, that soil erosion by water is complex and depends on the interactions of several other features such as vegetation cover, soil (preparation, type, moisture, and transport), the slope and size of the watershed, and the intensity and erosivity of the rainfall (Schick et al. 2000; Bartley et al. 2006; Santos et al. 2011). Otherwise, it is important to note that the values of surface runoff and sediment production by drag found here may have been influenced by higher rainfall than in previous years.

Chemical attributes of sediments produced by drag

The potential acidity and levels of OC and nutrients from sediments produced by drag as a result of the 57 rainfall events, varied between the watersheds (Table 5). In AGRS higher potential acidity of the sediment was found, which resulted in a lower pH value for the surface layer in this agro-ecosystem. As regards the OC content of sediment production by drag, it was found that the enrichment rate of the OC was higher in AGRS and may be related to the adopted management system: mowing and windrowing of straw for planting maize (*Zea mays* L.) in 2011.

The high level of phosphorus extractable of sediments collected on forested areas (MN and MR), where enrichment element rates (sediment per soil) reached up to 180.92 and 150.50 respectively. These high rates may be related to the sampling periods, being made at the end of the rainy season, when possibly phosphorus had been removed from topsoil. Lower rates of phosphorus were observed by Izidorio et al. (2005).

Higher Na levels was observed in sediment from PAST (Table 5), and no enrichment was evidenced in relation to the levels observed in the soil from the watershed (Table 2). Those nutrient levels in the soil may be attributed to the weathering of feldspars and plagioclases, common soils formed from crystalline rocks in semiarid regions.

Considering the sediment production by drag, the agro-ecosystems formed by MN and PAST presented higher levels of Ca and Mg respectively. The Vertisols typical of these systems also presented high levels of Ca and Mg, and that may result in alkalinity of the soil, as they are associated with low levels of H^+Al.

Higher K and Mg contend in the sediment from PAST may also be related to plant biomass decaying. Degradation of the plant structure promotes the return of minerals to the topsoil (Wick et al. 2000; Fernández et al. 2013).

In turn, the sediments from drag in AGRS showed high Fe, Zn and Mn levels (Table 5), which may be related to mineralogy of the parent material. Considering the different micronutrient levels in the surface

Table 5 Potential acidity, average organic matter and nutrient levels in sediments produced by drag from January to May 2011 in agro-ecosystems of the semiarid region, Iguatu

Nutrients	Units	Agro-ecosystems			
		MR	MN	PAST	AGRS
H^+Al^{3+}	$mmol_c\ dm^{-3}$	4.96 ± 2.0	6.83 ± 2.8	4.01 ± 1.6	40.58 ± 21.1
OC	$g\ kg^{-1}$	82.47 ± 191.9	117.90 ± 364.6	149.43 ± 197.3	229.75 ± 329.0
P	$mg\ kg^{-1}$	323.58 ± 85.3	340.13 ± 83.6	46.27 ± 8.3	11.70 ± 7.6
Na^+	$mmol_c\ dm^{-3}$	1.35 ± 0.3	1.29 ± 0.5	1.90 ± 0.8	0.68 ± 0.4
K^+	$mmol_c\ dm^{-3}$	3.42 ± 1.0	3.37 ± 2.6	3.56 ± 1.8	1.04 ± 1.0
Ca^{++}	$mmol_c\ dm^{-3}$	445.36 ± 126.0	462.27 ± 113.6	307.91 ± 103.1	73.27 ± 36.8
Mg^{++}	$mmol_c\ dm^{-3}$	121.74 ± 28.9	116.13 ± 32.7	138.73 ± 45.8	37.38 ± 8.9
Fe	$mg\ dm^{-3}$	0.91 ± 0.7	1.00 ± 1.3	9.04 ± 5.9	134.23 ± 77.2
Zn	$mg\ dm^{-3}$	0.52 ± 0.2	0.82 ± 0.3	1.82 ± 1.2	3.26 ± 5.2
Cu	$mg\ dm^{-3}$	2.05 ± 1.1	2.03 ± 1.8	1.67 ± 0.8	1.32 ± 1.0
Mn	$mg\ dm^{-3}$	20.42 ± 16.7	33.03 ± 42.6	58.40 ± 15.0	84.01 ± 26.0

Number of samples for: H^+Al^{3+}, OC, P, Na^+, K^+, Ca^{++} and Mg^{++} (MR = 23, MN = 21, PAST = 27, AGRS = 16); to Fe, Zn, Cu and Mn [MR = (8–23); MN = (5–21); PAST = (12–27); AGRS = (7–16)] layer of AGRS (Table 2), it can be seen that there were increases in content in the sediment produced by drag of 2.2, 4.3 and 6.7 times for Fe, Zn and Mn respectively. In turn, the increase in the Cu content of the sediment may be due to plant absorption, and the nutrient recycling. A high level of Cu was detected in sediment production by drag in the forested areas (MN and MR). It is worth pointing out that there is a direct relationship between the nutrient content in eroded soil and that of the surface layer of the watershed (Schick et al. 2000; Bertol et al. 2007).

Nutrient loss in sediments produced by drag

The nutrient losses from sediments produced by drag reached quite significant values, reaching 3.51 kg ha^{-1} Ca, 0.83 kg ha^{-1} Mg and 0.18 kg ha^{-1} P (Table 6). As for the micronutrients, losses of 5.46 g ha^{-1} Mn, 1.59 g ha^{-1} Fe, and 0.51 g ha^{-1} Cu were noted. Izidorio et al. (2005) found similar values.

More OC was lost from MR and MN areas a fact that is probably related to the greater erodibility of Vertisols when compared to Luvisols (Duiker et al. 2001) to the density and organic matter content of the surface layer (Schick et al. 2000; Lobato et al. 2009), to the soil management (Franco et al. 2002; Paudel et al. 2012) and to the volume of sediment lost by drag (Fraga and Salcedo 2004).

The macronutrient lose by drag obeyed the decreasing following order: Ca> Mg> P> K> Na (Table 6), and a similar sequence occurred in arid ecosystems (Izidorio et al. 2005; Díaz et al. 2011). We inferred that nutrient losses are governed by the volume of eroded soil and to a lesser extent by the levels of elements in the soil.

Losses of P in the sediment produced by drag exceeded those of Na and K. Such P level may be related to its presence of the element in light organic soil particles. Losses of extractable P from sediment produced by drag in forested areas can even be related to its recycling, since the organic P contend represents up to 65 % of the total detected in the soil, being partly linked to light clay minerals (Cassol et al. 2002). In turn, the Na and K are more soluble elements and more weakly adsorbed to soil colloids. Because they are of highly mobile in the soil, it is believed they are lost primarily when in solution. The losses of exchangeable Na and K (Table 6) were also influenced by the production of sediment by drag, being higher in thinned and natural forested areas. Aguiar et al. (2006) found more significant losses of Na and K from the soil in areas of Caatinga, as well as in the runoff water.

Other exchangeable ions, such as Ca^{2+} and Mg^{2+}, were detected in high levels in the sediment originating from MR and MN areas, showing similar results to those observed by Izidorio et al. (2005) and by Bertol et al. (2007). According to Wick et al. (2000) the nutrient content of the soil is influenced by the presence of MN. In AGRS, losses of P, Na, K, Ca and Mg were probably related to lower sediment production (Table 6), lower watershed soil content (Table 3) and their exportation in the corn field.

The micronutrients losses by drag followed the order Mn> Fe> Cu> Zn (Table 6); differing from the

Table 6 Loss of organic carbon and nutrients from sediments produced by drag from January to May 2011 in agro-ecosystems of the semiarid region, Iguatu

Nutrients	Units	Agro-ecosystems			
		MR	MN	PAST	AGRS
OC	kg ha^{1}	77.71 ± 28.6	46.63 ± 15.9	28.83 ± 9.6	6.09 ± 2.4
P	g ha^{-1}	182.24 ± 38.8	114.84 ± 23.9	11.35 ± 2.4	0.30 ± 0.1
Na	g ha^{-1}	18.08 ± 3.8	9.33 ± 1.9	9.86 ± 2.0	0.41 ± 0.1
K	g ha^{-1}	76.91 ± 16.5	42.66 ± 8.5	30.89 ± 6.3	1.04 ± 0.3
Ca	g ha^{-1}	3,518.66 ± 1,078.0	1,920.39 ± 651.6	1,153.89 ± 355.5	34.02 ± 9.2
Mg	g ha^{-1}	834.08 ± 175.0	471.17 ± 99.1	466.52 ± 94.7	12.18 ± 2.7
Fe	mg ha^{-1}	261.59 ± 51.3	49.15 ± 18.2	839.63 ± 239.0	1,596.12 ± 411.0
Zn	mg ha^{-1}	131.74 ± 31.8	88.54 ± 26.6	168.11 ± 52.1	43.23 ± 9.5
Cu	mg ha^{-1}	516.18 ± 147.1	273.17 ± 73.0	135.43 ± 36.5	7.11 ± 2.9
Mn	mg ha^{-1}	5,036.21 ± 1,414.2	5,465.24 ± 1,154.0	5,047.24 ± 1,337.0	729.90 ± 306.7

sequence observed in the soil: Fe> Mn> Cu> Zn (Table 2). Losses of Mn and Cu were certainly influenced by the sediment production (Table 5). In contrast, the loss of Fe and Zn was higher in AGRS and PAST, respectively, and it led to suggest distinct behaviors for nutrient loss in agrosystems. Aguiar et al. (2006) found the following order for micronutrient losses: Fe> Zn> Mn> Cu. For the loss of micronutrients, Cassol et al. (2002) partially agreed, but nutrient losses are not directly related to soil and water contends. The interaction of Zn and Mn with OC may cause the formation of organic complexes that can be transported (Tsai et al. 2003).

Multivariate analysis of the principal components of the variables of the sediments allowed biplots building with two loading factors (Fig. 2). These groups formed distinguish the watersheds and land use systems. Component 1 explains 78.68 % of the total variance for MR, MN and PAST with positive values, and with a negative value for AGRS. Component 2, which explains 19.82 % of the total variance, shows positive values for MR, MN and AGRS, and a negative value for PAST. This suggests that the MR, MN and PAST watersheds had similar behavior as regards sediment production, differing from AGRS. Such results are mainly explained by the

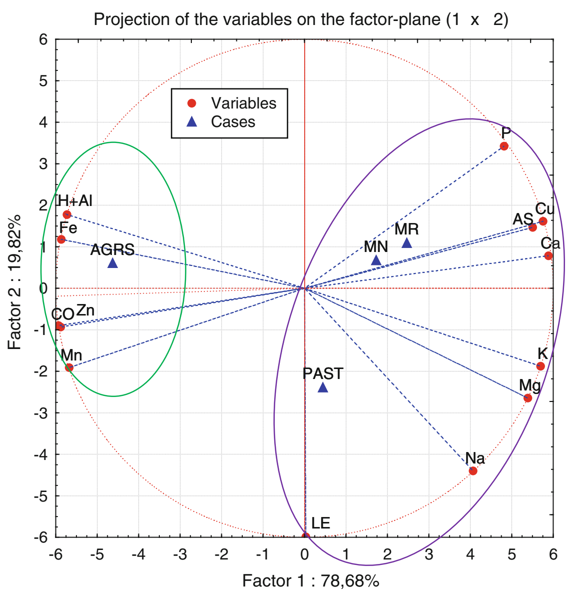

Fig. 2 Analysis of principal components for the chemical properties and sediment losses during the rainy season of 2011 in agro-ecosystems of the semiarid region, Iguatu. (*LE* surface runoff, *AS* sediments produced by drag, *CO* organic carbon)

characteristics of the Vertisols in MR, MN and PAST and of the Luvisol in AGRS.

The variables influenced positively were described by the factor 1 loading for MR, MN and PAST are: K, Mg, Na, Ca, Cu, P, and runoff depth and sediment loss. AGRS assumed negative value for potential acidity, contends of Zn, Mn, Fe and OC. Differences between variables of the groups identified with circles on Fig. 2, are attributed to edaphic factors, which according to Díaz et al. (2011), are related to the erodibility, soil type, and activity of clays, the presence of abrupt textural change, the silt to clay ratio (>2), cation-exchange capacity, base saturation, OC and nutrient levels in the soil and in the sediments produced by drag. Furthermore, along the axis of loading factor 2, we observed that positive variables differed the forested areas (MR and MN), were the levels of P, Cu, Ca and of sediment loss. In AGRS there was a positive contribution of the potential acidity and Fe content, while levels of OC, Zn and Mn negatively affected the differentiation of the sediment. However, the levels of K, Mg and Na, and the depth of runoff that were seen in PAST, assumed negative values in Fig. 2. This demonstrates that land use type can be a decisive factor in the levels of these variables in soil (Fraga and Salcedo 2004; Aguiar et al. 2006; Lobato et al. 2009; Sousa et al. 2012) and sediment produced by drag (Vacca et al. 2000; Bartley et al. 2006).

Conclusions

The greater erodibility of the Vertisols (from forested and grassland areas) in relation to the Luvisol in the system of subsistence farming, promotes higher yields of sediment production by drag, regardless of the vegetation typical of the semiarid region and the traditional systems, and of the number of events that generated surface runoff.

Ecosystems with natural hyper-xerophylic Caatinga vegetation are unable to dissipate the erosivity of the rainfall or avoid greater impact of rain on soil disaggregation and the transported of sediment may affect the sediment production from drag, whereas the systems of PAST and of AGRS with reduced soil tillage, promote increases in the depth of the surface runoff and in the organic matter content of the sediment respectively.

The loss of nutrients in agro-ecosystems of semi-arid region is governed by the volume of eroded soil with rainfall, and the losses follow in descending order: Ca> Mg> P> K> Na> Mn> Fe> Cu> Zn.

The management and conservation of soil and green roofs in watersheds should be taken into account in developing policy and plans for sustainability in the semiarid region.

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